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JAN 76 J W NEWHARD, G T ARMSTRONG   F33615-75-C-5127

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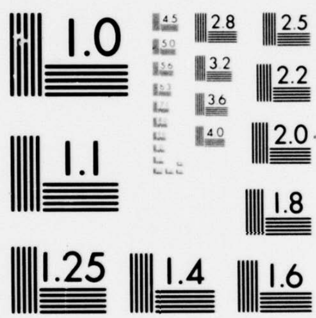

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AIRCRAFT SIMULATOR COMMONALITY STUDY
COMPUTATION SYSTEM SELECTION CRITERIA AND MODEL
EXECUTIVE SUMMARY

SINGER - SIMULATION PRODUCTS DIVISION
1077 E. ARQUES AVENUE
SUNNYVALE, CALIFORNIA 94086

JANUARY 1976

TECHNICAL REPORT ASD-TR-77-26

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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RICHARD E. WORTHEY
Program Manager

FOR THE COMMANDER

HENRY J. STACHOWSKI
Technical Advisor
Deputy for Development Planning

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ASD-TR-77-26	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Aircraft Simulator Commonality Study Computation System Selection Criteria and Model, Executive Summary		5. TYPE OF REPORT & PERIOD COVERED Executive Summary, 23 January - 9 December 1975
		6. PERFORMING ORG. REPORT NUMBER UC-7257 (ES)
7. AUTHOR(s) Jack W. Newhard, Glenn T. Armstrong		8. CONTRACT OR GRANT NUMBER(s) F33615-75-C-5127
9. PERFORMING ORGANIZATION NAME AND ADDRESS Singer - Simulation Products Division (APO) 1077 E. Arques Avenue Sunnyvale, California 94086		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project A-167 DI-S-3591/S-117-1
11. CONTROLLING OFFICE NAME AND ADDRESS Aeronautical Systems Division Attn: ASD/XRU Wright-Patterson AFB, Ohio 45433		12. REPORT DATE January 1976
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) 21p.		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aircraft Simulators, Digital Computers, Computational System Selection Aids

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Digital computer selection practices in USAF simulator procurements were reviewed. Information about operational aircraft simulators was obtained from fourteen USAF bases, four of which were visited by the authors. A model was formulated which employs six categories of criteria for assessing, from the USAF point of view, the relative merits of candidate computer systems for application in USAF flight training simulators. The model was implemented in FORTRAN IV and installed on the CDC-6600 computer system at Wright-Patterson AFB, Ohio. Preparation of a comprehensive data base tape file for use with the program similar to an example used in program checkout is recommended.

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SECTION I

INTRODUCTION

The purpose of this study is to develop and implement a model to aid in the choice of computational systems for aircraft simulator crew training devices. This requires the identification and organization of computational system requirements and Air Force aims and philosophy. Once these are recognized and characterized in terms of computer attributes, a model can be devised to judge candidate computer systems. Attention was focused on those attributes which define the central processing unit of a computer and those items which determine the computer's ability to cost-effectively handle the simulator processing load and promote commonality in the Air Force inventory. During the course of this study, Singer was furnished information as an aid in choosing selection criteria and identifying Air Force aims, interests and philosophy. The information was in the form of specifications, contractor submitted proposals for specific simulators, guidelines for evaluating proposals and MIL-STD-876A. Four generalized lists of variables prepared by Air Force Logistics Command (AFLC) and a copy of a conceptual plan formulating incentives for reducing operating and support costs were also provided and were considered in preparing the "costs" portion of the model. Information about simulator use was collected from questionnaires sent to numerous Air Force simulator sites. Personal visits to simulator bases were made by Singer personnel to obtain insight and information not easily covered by a questionnaire and to allow Air Force personnel to volunteer ideas which may not have occurred to the investigators. Information from these many sources was pooled with the personal experience of those directly involved in the study. The result was a model formulated to rank candidate computers in their abilities to perform simulator processing tasks. The model was implemented in the form of a computer program named "CRITIC." "CRITIC" is an acronym for Candidate Ranking and Inventory Traits Inspection for Commonality.

SECTION II

REVIEW OF COMPUTATION SYSTEM SELECTION PRACTICES

MIL-STD-876A (USAF), "Military Standard -- Digital Computation Systems for Real-Time Training Simulators" dated 8 July 1971, ". . .covers the general characteristics and configurations of digital computation systems used in (USAF) real-time training simulators and the general guidelines for mathematical models." This standard, which supersedes MIL-STD-876 (USAF) of 21 February 1967, is ". . .mandatory for use by all activities under the cognizance of the Air Force effective as of date of issue." In reviewing these standards, we discerned a need for flexibility in computer system selection criteria specification and application in our model. Obviously, the model should recognize "requirements" as one category of selection criteria. Also, some allowances should be made for "preferences" which may be satisfied in varying degrees as opposed to the more limited interpretation of "requirements." "Preference" criteria can be subdivided or associated with differing incremental values (weights) with respect to "commonality," "low risk," and "support objectives." These, together with "requirements," "performance," and life cycle cost evaluations, are considered to comprise an adequate set of categories of criteria to be included in the model.

Excerpts relating to digital computation systems from specifications for C-141A, T-37 and T-38, A-7D, F-15A, and CH-3E and HH-53C aircraft simulators were reviewed. The trend has been toward more explicit statements in terms of performance requirements and particular main frame computer systems characteristics. Also requirements specified for spare time, spare memory, and spare input/output (I/O) channels, etc., have increased from 10%, 10%, and 10% to 25%, 25%, and 15% respectively. In addition, the more recent specifications have been more explicit than MIL-STD-876A in the manner in

which the spare time requirement shall be met. We decided the model should accept spare time and memory requirements as input parameters for candidate computers' merit assessment and to apply the MIL-STD-876A parameters independently.

Excerpts from successful bidders' proposals for the T-37 and T-38, A-7D, F-15A, CH-3E and HH-53C aircraft simulators were also reviewed. In each case, the computer system selected employed one or two general purpose digital computers having a 24-bit word length. With one exception, the computers selected were different models built by the same computer manufacturer, Datacraft, now a subsidiary of the Harris Corporation. The exception was a dual Honeywell DDP-324 configuration for which a single Datacraft 6024/1 configuration was substituted during the A-7D simulator development. A variety of other machines were considered as candidates, among which 16, 18, 24, and 32 bit word lengths were represented.

Computer system hardware cost (predominantly central processor, processor options, and core memory) was a primary factor in selecting main-frame computers (or eliminating others from further consideration) from those candidates which were capable of being configured to handle the estimated processing load and with the specified spare capacity requirements. Other factors affecting development and life cycle costs were considered in varying degrees. Total costs of some items such as computer system hardware increase with the number of identical systems procured. Costs of other items, such as software programming (both for initial development and for life-cycle modifications), do not. Cost factors as quantified in relative terms in the various technical proposal excerpts are an insufficient basis for assessing candidates in general. In future procurements additional cost-related factors may reasonably be expected to influence the selection. For this reason, provision was made in the model to allow a wider variety of cost estimates to be included.

Analyses relating to application of computer system performance criteria were apparently performed in essentially the same manner, although some of the relevant details were not always presented within the references furnished for review. The general approach consisted of defining a number of functional "modules" which collectively characterized the real-time simulation computational load in terms of instructions per second and storage requirements for programs and data. The instructions per second figures were derived from products of module execution frequency and number of instructions executed within the module (including internal loops) representing some heavily loaded or worst case situations. Differing conventions may have been employed with respect to instructions, constants, parameters and variables of various types in storage requirements estimation. However, estimated storage requirements were generally expressed in words with some appropriate accounting for partial word and/or multiple word data elements and/or instructions. It was decided to permit computational load estimates to be input to the model in modular fashion so that the functional breakdown, if desired, could be included in the computer listing of the model input. This would still enable total loading estimates to be input as fictitious "modules."

Computational capability of the various candidates were generally represented in terms of instructions/second capacity of one or multiple processors with some appropriate accounting for memory access delays due to input/output, indexed or indirect memory reference, etc. Instructions/second capacity for a given processor was inversely related to a weighted average instruction execution time. In essence, a set of representative instructions, characterizing the overwhelming majority of actual instructions used in a simulation problem, were each assigned a probability of occurrence in a simulation problem based upon data from previous presumably similar simulations. These weight factors are generally referred to as "usage" factors and the

set is generally referred to as a "simulation mix." The effective time for a given processor to execute each representative instruction is multiplied by the corresponding instruction mix usage factor. The products are then summed to obtain the weighted average instruction execution time. We extended this approach in our model, by permitting several instruction mix sets to be used in characterizing a collection of software modules. This enables software modules which may have significantly different characteristics to be associated with different instruction mix sets.

SECTION III

DATA FROM USAF SIMULATOR INSTALLATIONS

The Statement of Work under which this study was performed stipulated that data be gathered from simulator facilities at Plattsburgh, Myrtle Beach, Altus, and Hill Air Force Bases. To facilitate this data gathering, we mailed sets of data collection forms, "Questionnaires," to cognizant USAF personnel at the respective simulator facilities. These seven page questionnaires incorporated a number of contributions from the USAF study team. The completed questionnaires provided a convenient basis for further discussions during our visits at the bases. Early in the study it was decided that the data base might be significantly enhanced if questionnaire responses from additional USAF simulator installations were also obtained, even though follow-up visits could not be made within the scope of the study contract. Accordingly, cooperation was requested by the USAF study manager and questionnaire responses were subsequently obtained from ten additional USAF bases. As responses were received, a copy of each was forwarded to the USAF study manager. A copy was also forwarded to the corresponding simulator contractor so their cognizant people might have the opportunity to amplify or clarify the information therein. Annotated questionnaire responses are presented in the Data Supplement to the Final Report. Annotations reflect contractor review, follow-up visits, or both. Additional information obtained during the follow-up visits (e.g., organization charts) is included with the corresponding questionnaire responses in the Data Supplement.

Simulator installations at Plattsburgh, Myrtle Beach, Altus, and Hill Air Force bases were visited during the period May 12-23, 1975. Personnel at each facility were cooperative even though these visits were imposing additional demands on their time. Approximately a day

and a half was spent at each base observing simulator and computer operations, reviewing questionnaire responses, and gathering additional information relevant to hardware and software maintenance and support. Much of the information was received from informal discussions with USAF military and civilian personnel. Our attention was focused on growth history, maintenance and support of the computational systems, with primary emphasis on hardware and software employed in the main computer(s). Additional information was sought concerning the overall simulators so the findings would be presented in proper perspective.

Two FB-111A mission simulators are located at Plattsburgh AFB; a third is located at Pease AFB. Each of these includes one replica of the FB-111A cockpit containing pilot and navigator stations on a five degrees-of-freedom motion base. Each mission simulator incorporates three Xerox Data Systems (XDS) Sigma 5 central processing units (CPU's) in a multiprocessor configuration with a total of 132K 32-bit words of core memory. (NOTE: $K=2^{10} = 1024$ is used consistently in this summary.) CPU's A, B and C share 16K words via a six-way access port and have private memories of 40K, 44K and 32K words, respectively. A Raytheon 703 minicomputer and a Singer digital target generator (DTG) are employed as auxiliary processors in conjunction with the tactics simulation. The FB-111A Bomb/Nav simulator is less complex; in essence, most pilot instruments and controls are inactive and the cockpit replica is situated on a fixed base. The computation system includes two XDS Sigma 5 CPU's with a total of 76K 32-bit words of core memory, a Raytheon 703 and a DTG.

Simulator training costs associated with primary personnel, operation and maintenance and utilities were stated to be in the neighborhood of $165/hr. Approximately sixty USAF personnel provide on-site

maintenance and operations support for the three simulators at Plattsburgh. Of these, twelve have had a year or more experience with this equipment. (The FB-111A mission simulators have been on-site for nearly 5 years.) Approximately 680 hours of specialized on-site training (70 - 75% classroom, 25 - 30% on-the-job) is given new recruits after completion of the appropriate Air Training Command (ATC) technical training course for simulators (i.e., approximately 32 weeks of 342 "Flights" or 35 weeks of 343 "Tactics" schools). Significant amounts of on-site training is also required by personnel who have been reassigned from other USAF simulator installations where the computation equipment is substantially different. Much of the on-site training is conducted or aided by AFETS personnel. Most of the troubleshooting and other unscheduled maintenance is accomplished or guided by the on-site field service representatives.

One A-7D simulator is located at Myrtle Beach AFB. Four duplicate simulators are located at Davis-Monthan AFB (Arizona), England AFB (Louisiana), Rickenbacker AFB (Ohio), and Buckley AFB (Colorado). Each of these includes one replica of the single-seat A-7D cockpit on a four degrees-of-freedom motion base. One Datacraft 6024/1 CPU with 48K 24-bit words of core memory is incorporated in each simulator. The Myrtle Beach computer complex includes a keypunch, card reader, line printer, and disc drive in addition to the peripherals (paper tape reader, paper tape punch, ASR-35 and KSR-35 teletypewriters, and disc drive) included in the other complexes.

On-site maintenance and simulator operations support is accomplished by 15 USAF personnel (including three administrators) and one field service representative. It was mentioned that a Civilian Technical Assistant (CTA) was being sought to augment the staff for continuity in maintenance training. Approximately one year of classroom and hands-on training (after 36 weeks of technical school) is required

to qualify a maintenance technician for independent work on this system. About 2.5 months of this is devoted to computer training. Assembly and machine language familiarization is included in the course requirement; compiler familarization is made available as an option. A three-man Development Technician Team (DTT) presently at the Myrtle Beach A-7D simulator facility provides key organic support for this and the other A-7D simulators used by TAC. Their role in simulator hardware and software change implementation and in related development efforts varies depending upon the nature of the change. Arrangements have been made with the computer vendor (Harris Corporation, which assimilated Datacraft) for on-call service when special computer system repairs are required. This has been exercised several times since installation of the first three simulators.

Three C-141A simulators are located at Altus AFB. Five additional C-141A simulators are operational at other bases. Each includes one replica of the C-141A cockpit with pilot, co-pilot and flight engineer stations and two onboard instructor stations on a four degrees-of-freedom motion base. Six of the eight C-141A simulators each incorporate one Systems Engineerings Laboratories (SEL) 840 MC computer with 44K 24-bit words of core memory. Two of these simulators are at Altus. Two of the eight C-141A simulators were supplied with two Control Data Corporation (CDC) 924 computers in each. Each of these systems incorporates a total of 48K 24-bit words of core memory including 16K words added since installation. One of these simulators is at Altus. Two C-5A simulators are located at Altus AFB. Three additional C-5A simulators are located at Dover AFB (Delaware) and Travis AFB (California). Each includes one replica of the C-5A cockpit with pilot, co-pilot, flight engineer, and navigator stations and three onboard instructor stations on a four

degrees-of-freedom motion base. These simulators each incorporate one SEL 840A computer and one SEL 840MP computer with 32K and 40K words of 24-bit core memory, respectively, including 8K words added since initial installation.

Cost per hour of training time in the C-141A and C-5A simulators was stated to be $92 and $126, respectively, excluding the use of visual systems. Cost per hour of visual systems (4 cockpit displays plus 2 camera-models, etc.) usage was stated to be $80. Cost per hour of training in a C-5A aircraft was stated to be in the neighborhood of $3600. Three-shift operation and maintenance support for the five flight simulators at Altus AFB is provided by 45 personnel. In addition nine people are assigned for visual system maintenance. Four people are assigned to a maintenance and engineering prototyping group "Mod Squad" whose function is similar to that of the DTT for TAC simulators. Maintenance and operations technicians receive technical school (i.e., basic flight/tactics simulator school) follow-up training in a program which alternates classroom work and hands-on experience in sessions several weeks in length. The course includes the academic portions of the ground school training received by aircrew personnel. A list of the in-house training courses and the number of hours associated with each precedes the questionnaire responses from Altus in the Data Supplement. With the exception of "Mod Squad" prototype work, the overwhelming majority of simulator maintenance effort at Altus was stated to be devoted to equipment other than the digital computers.

It was suggested that overall life cycle costs might be reduced if specifications incorporated more stringent I/O system design requirements. Prohibiting power supplies to be loaded above 75% or even 50% of rated capacity in order to prolong their useful life was an example specifically proposed. It was suggested that a detailed

study of the I/O interface systems (convertors, multiplexors, relays, cables, connectors, etc.) might be more beneficial to the USAF than the present study. Such a study would presumably investigate presently available equipment and system design alternatives (e.g., individual vs. multiplexed A/D and D/A convertors) and recommend specification standards aimed at overall life cycle cost reduction. Additional relevant suggestions are included in the questionnaire response from McGuire AFB in the Data Supplement. It was noted during the discussions that the autopilot and fire suppression systems were the only features which had been incorporated in the simulators prior to their installation or use in the actual aircraft. The desire was expressed to have all simulator changes precede or at least parallel aircraft system changes for maximum training benefit. We were informed that the need to update radio station data in the simulators was usually discerned by aircrew personnel who noticed differences between simulated and real-world station parameters. Altus personnel suggested that this situation could be improved upon considerably if a standard library of radio station parameters were maintained in computer compatible format and/or if periodic change notices were made available to using installations in a standard format which could be converted into whatever specific internal formats are required. Thus, for example, updating of radio aids data for each of the C-141A and C-5A simulators could be done at Altus AFB in a systematic and highly mechanized manner.

The CH-3E and HH-53C simulators at Hill AFB are one of a kind training devices. Each includes a replica of the respective helicopter cockpit on a six degrees-of-freedom motion base. The CH-3E includes pilot, co-pilot, and instructor stations and the larger HH-53C also includes a flight mechanic station. Instructor stations are of the keyboard-CRT type. These simulators each incorporate one Datacraft

6024/3 CPU with 40K 24-bit words of core memory with an ASR-35 teletypewriter and a moving head disc. A card reader and a line printer are also attached to the CH-3E's computer. We were favorably impressed by the compactness and flexibility provided by the keyboard-CRT instructor station. We were told, however, that the instructors consider the necessity of altering some simulation variables such as wind speed and direction via the keyboard to be a serious disadvantage.

Simulator operation costs approximately $29/hour including maintenance, supplies, utilities, etc., and excluding instructor and trainee costs. Comparable cost for helicopter operation was stated to be $557/hour. All-inclusive costs for simulator training were stated to be approximately $107/hour. An organization chart showing authorized and assigned personnel categories for administration, aircrew instruction, and maintenance at the helicopter simulator facility is included with the questionnaire responses in the Data Supplement. Six USAF personnel are assigned to the maintenance section.

At the various simulator facilities sampled, software modifications were generally associated with aircraft configuration changes, gaming area data changes (e.g., addition or deletion of radio stations and/or alteration of station parameters), correction if discrepancies between simulator and aircraft systems and additions to enhance training (e.g., introduce new malfunctions for instructor selection) or increase operational convenience (e.g., add a pre-programmed mission). USAF personnel at most of the installations reported an average program modification frequency of once per month. A lower figure, three to four modifications per year, was reported for the F-4E simulator at Chanute AFB and flights modules were stated to be those most often modified. In contrast, a monthly average modification frequency was reported for the F-4E simulator at Eglin AFB and tactics modules therein were stated to be those most often modified. Both

sites reported the modifications involved both hardware and software changes. The Eglin AFB response attributed the modifications to aircraft configuration changes. The discrepancy in reports for presumably identical simulators may reflect substantially different time periods spanned by the "averages." Weekly software modifications were reported to occur in the F-111D simulator at Cannon AFB and in the F-111F simulator at Mountain Home AFB. A tabulation indicating a total of 1466 cumulative software patches associated with various simulation routines in the FB-111A mission simulator was obtained at Plattsburgh AFB approximately 55 months after installation. The corresponding average is 26.7 patches per month. The majority of these 1466 patches were associated with navigation (21.3%), countermeasures (21.2%), bombing (17.5%) and flight (12.8%); twelve additional categories of functional routines each had 6.2% or fewer patches (27.2% of total). Software in the *Advanced Simulator for Undergraduate Pilot Training* (ASUPT) is subject to "continuous" modification according to the questionnaire response from Williams AFB which reported modification efforts concentrated on motion, flight, and g-seat simulation ranging from "minor changes in the data base or some k-factor to complete redesign of an entire module." The ASUPT is being employed as a research tool by Air Force Human Resources Laboratory (AFHRL) as originally intended; it is the "youngest" simulator included in the survey. Software in the Simulator for Electronic Warfare Training (SEWT) at Mather AFB is reportedly modified "to meet changes of training criteria and improve training equality" (no frequency given) and modules dealing with printed output, student evaluation, and equipment displays are those most often modified.

SECTION IV
MODEL AND PROGRAM DEVELOPMENT

Computer selection criteria were organized into a model which was implemented in the FORTRAN IV language. The program was tested on an in-house computer. Several source card changes enabled the program to be demonstrated and installed at the CDC-6600 facility in Building 676, Area B, at Wright-Patterson AFB.

The CRITIC (Candidate Ranking and Inventory Traits Inspection for Commonality) computer program provides:

1. Computation assistance in estimating computer-related costs for a specified simulator procurement. Separate CRITIC runs can compare candidates on the basis of cost projects made for prototype development, procurement cycle, or for the anticipated life cycle of the simulator;
2. Computation assistance in estimating computer loading requirements, and assessment of candidate configurations' responsiveness in terms of spare time and memory provisions (including multicockpit, multiprocessor and multicomputer configurations);
3. A systematic and flexible means of reviewing computer systems in the USAF inventory with respect to meeting required characteristics (i.e., identifying potential candidates) and assessing commonality among systems in inventory;
4. A systematic and flexible means of assessing each candidate system's merit from the standpoints of possessing required characteristics, commonality with USAF inventory, low risk, and potential for meeting USAF support objectives over the simulator life cycle. These and cost-performance merit are combined in an overall merit rating for each candidate;
5. Ranking of candidate computer systems in each merit category.

SECTION V
CONCLUSIONS

It is concluded that the CRITIC model and computer program can be a useful tool to aid in the selection of computers for use in USAF simulators. One important aspect of its usefulness is the built-in flexibility which enables the program to adapt to changing numbers of criteria in various categories and values of the associated weighting factors, and even the nature of characteristics of inventory and candidates. The basic structure of the attribute tables and the method of characteristics testing is such that the qualitative definitions of most of the listed values can be altered to suit the needs of future evaluations (and the corresponding tabular data quantifying same can be altered accordingly) in a manner transparent to the program. Also, since the program is written entirely in FORTRAN IV and all input data (both DATA BASE TAPE and RUN INPUT DECK) are in 80-column Hollerith card image form, the program and its data base media are readily adaptable for use in a wide variety of computer installations. (Minor modifications enable the CRITIC program to be run in a machine which has at least 24K core words of 24-bits or greater and whose FORTRAN IV compiler supports DECODE statements.)

It should be emphasized that the CRITIC program is a <u>tool to aid in selection of computers</u> and not a computer selector or a contractor selector. As such it can reasonably be expected to focus attention on apparent strong points or weak points of various candidate configurations in a uniform manner. Like other computer programs, it is susceptible to the GIGO (garbage-in, garbage out) syndrome. Careful and objective scrutiny of all candidate configuration characterizations (likewise, inventory computer characterizations), as well as the candidate-dependent cost-related inputs should maximize the validity of the candidate rankings.

SECTION VI
RECOMMENDATIONS

Complete characterization of the digital computers in the USAF simulator inventory was beyond the scope of the present study. We have supplied a card deck which served as the primary medium from which a "DATA BASE TAPE" was created for CRITIC program verification. A listing of the deck is included in the CRITIC program documentation. A comprehensive DATA BASE TAPE may be prepared following this example. The necessary data for preparing these representations (attributes data tables) may be accumulated from a variety of sources including computer vendor publications, simulator procurement and verification records, GSA catalogs, AFLC inventory data, and simulator vendors. We recommend that the USAF take appropriate action to initiate preparation of a comprehensive DATA BASE TAPE and to institute procedures for its periodic review and updating (to reflect inventory changes, revised computer system specifications, etc.) consistent with anticipated usage of the CRITIC program.

Before encoding additional computer system descriptions in conjunction with preparation of a comprehensive DATA BASE TAPE, consideration should be given to augmenting the computer attributes definition list (i.e., assigning some additional definitions to various "spare" table entries) and rearranging some of the items in the table. Time constraints for checkout and delivery of the program precluded our doing a second iteration on the attributes table layout. A review of this area is desirable to enhance the information content of the characterizations and to effect more optimum grouping of table entries. The latter should facilitate preparation and checking of the associated data for both inventory and candidate computer systems.

There are some areas related to this study but beyond its scope which we believe merit further investigation. They are:

1. How effectively can higher level languages such as FORTRAN be used in real-time simulator programs? There are some obvious benefits from relative ease of program development and maintenance. There are also penalties for high level language use such as requirements for additional memory, CPU time and peripheral devices. Consideration should be given to developing standard means whereby these benefits and penalties are measured (via benchmark programs, relative programming cost assessments, etc.) and the overall benefit (or penalty) calculated. Appropriate standards should also be developed for rating computer vendors' compilers for generating code to be used in real-time simulation.

2. Should all simulator systems use a common data base, data format and preprocessor for the preparation, updating, and dissemination of navigational aid data? Updates seem too often initiated as a result of instructor-pilot or trainee reports to the personnel at the simulator site that the simulator no longer correctly represents the real world aids. This seems to be a sufficiently widespread and frequently occurring simulator data change activity to warrant investigation of means of expediting updates in a uniform manner.

3. Should I/O interface equipment and interconnection standards be revised or augmented? More explicit specification requirements were advocated at Altus AFB and some specific suggestions were offered. A more detailed review of this particular area seems advisable.